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HUMAN BODY DENSITY AND FAT OF AN ADULT MALE POPULATION AS MEASURED BY WATER DISPLACEMENT

Harry J. Krzywicki, et al.

Fitzsimons General Hospital
Denver, Colorado

21 July 1966

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LABORATORY REPORT No. 297

HUMAN BODY DENSITY AND FAT OF AN ADULT MALE POPULATION AS MEASURED BY WATER DISPLACEMENT

21 JULY, 1966

US ARMY MEDICAL RESEARCH AND NUTRITION LABORATORY

FITZSIMONS GENERAL HOSPITAL
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LABORATORY
REPORT NO. 297

21 July 1966

Project Number:	3A014501B71R Research in Biomedical Sciences
Task No.:	02 Internal Medicine
Work Unit No.:	061 Work Performance and Body Composition as Related to Environment and Nutritional Status

HUMAN BODY DENSITY AND FAT OF AN ADULT MALE POPULATION AS MEASURED BY WATER DISPLACEMENT

By

Harry J. Krzywicki
Chief, Body Composition Branch
Bioenergetics Division

and

Kenneth S. K. Chinn
Physiology Division

US Army Medical Research and Nutrition Laboratory

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ABSTRACT

Laboratory Report No. 297
Project No. 3A014501B71R Research in Biomedical Sciences
Task No. 02 Internal Medicine
Work Unit No. 061 Work Performance and Body Composition as Related to Environment and Nutritional Status

Body volume was measured on 14 male adults at 7 intervals during a 24 hour period using a water displacement technique. The variation in body densities fell within the accepted limits of error propagated by the technique. Body densities were also performed on 173 male adults ranging between the ages of 17 - 69. Values were effectively ranked in terms of age and body fat, demonstrating a continued increase in body fat with an increase in age. These values were independent of body weight.

The human body volumeter is a simple, rapid and effective device which compares favorably with the underwater weighing technique for estimating body density in large populations. The precision for estimating body fat is ± 0.488 kg when the residual lung volume is measured but is reduced to ± 1.52 kg when the residual lung volume is estimated.

BODY OF REPORT

WORK UNIT NO. 061: Work Performance and Body Composition As Related to Environment and Nutritional Status

Human Body Density and Fat of an Adult Male Population as Measured by Water Displacement

PROBLEM

No single method for estimating the 4 main components (fat, water, protein and mineral) of the human body exists although several techniques are available for approximating any one compartment. Routine body volumes for computing body density, measured by somewhat complex underwater weighing methods have had wide acceptance but require semitrained subjects for reproducible results. A simple, more expedient method described by Huff and Feller (1) and again by Allen, et al (2) measures the body volume by direct water displacement, in a calibrated tank. Information on the accuracy and reproducibility of this technique by repeated observations on the same subject is lacking. This study was designed to evaluate the limitations of the technique before additional body composition data of a mixed population was to be reported.

BACKGROUND

Systematic attempts to characterize and estimate the main anatomical, compartmental or chemical components of the human body mass have been reviewed by Keys and Brozek (3), Brozek and Henschel (4), and Brozek (5). Although the visual quantity of body fat is a crude index of nutritional status, the role of adipose tissue, the most variable component of the human body, requires further study in both normal and disease states. The discrimination of body fat from the other components of the whole body is important in the study of body composition of the individual or of various populations. The various procedures used for estimating body fat depend, ultimately, upon the derivations of equations that permit approximation of the fat compartment. Of the many existing fat estimating equations, Damon and Goldman (6) were able to densitometrically validate two of 10 equations tested.

A simple rapid and accurate measurement of body volume for computing body density is desirable for laboratory or field use. Robertson (7) was the first to have reported on the measurement of body volume employing water displacement. Two centuries later, Huff and Feller (1), and Allen, et al (2) described the construction and use of a body volumeter based on water displacement. Details of the construction and operation of the device have been reviewed by Consolazio, et al (8). Garn (9) reported on the construction of a transparent body volume tank and its readout accuracy but made no mention of human body volume data. Nagamine (10) described the body density and percent body fat of Japanese students as estimated from direct water displacement volumetry. The present study attempts to evaluate the accuracy and reproducibility of repeated body volumes measured by water displacement on a group of subjects and then presents data on the estimated body fat of a random male adult population.

APPROACH TO THE PROBLEM

The human body volumeter in use at this Laboratory had undergone very minor changes since it was originally described by Allen, et al (2) but the method of calibration is somewhat different. Aliquots of water were drawn off into a two liter volumetric flask from the portion of the volumeter served by a water level manometer. Centimeter scale changes in the manometer were recorded for each two liter change in water level. The factor obtained from the calibration was used for all human body volumes subsequently measured.

Body volumes obtained by direct water displacement include the errors contributed by the residual volume of air in the lungs following a forced maximal expiration as well as the volume of the gastrointestinal gas. Residual lung volume can be measured and reproduced to within 100 ml by the nitrogen washout method of Rahn (11) or it can be estimated using Chinn and Allen's (12) predicting formula. No accurate technique exists for the direct determination of gastrointestinal gas volume but the volume of 125 ml, suggested by Bedell (13) is generally accepted. However, Blair, et al (14) have reported maximal values of gastrointestinal gas as high as 2600 ml.

Two groups of adult males were studied. The first group was composed of 14 males from 21 - 47 years in age, and from 46.8 - 79.2 kg in body weight. This group was observed at 4 hour intervals over a period of 24 hours to test the reproducibility of body volumes as well as observe the trends in volume changes that might be attributed to gastrointestinal gas formation when on ad libitum food intake. The second group of 173 males ranged from 17 - 69 years in age and from 55.9 - 117.7 kg in body weight. The body volumes of this group were measured once and were used to assemble data on body composition changes with respect to aging. This group consisted of civilian and military volunteers from our Laboratory and Fitzsimons General Hospital.

Body heights of both groups were recorded to the nearest 0.1 cm on a centimeter rule and body weights were recorded to the nearest 0.05 kg using a Toledo scale (Model 2071) or Plima scale. Arm and scapula skinfolds were measured with the USAMRNL calipers (15). Residual lung volumes were computed from Chinn and Allen's (12) formula which incorporates body weight, age, and the average of the bilateral arm and scapula skinfolds. Gastrointestinal gas was not considered in the gas free body volume. Body fat was calculated from Allen's (2) formula wherein percent body fat = [4.834/density - 4.366] . 100.

RESULTS

The calibration of the body volumeter by repeatedly drawing off two liter aliquots of water and noting the manometer scale changes resulted in a factor of 2.100 ± 0.014 liters/cm. The water level manometer is backed by a machine engraved centimeter rule (0.05 cm graduations) and could be interpolated to 0.01 cm with the aid of an enlarging lens. Each 0.01 cm represented 0.021 liters of volume. Error propagation based on two manometer scale readings and the subject's ability to effect a forced maximal expiration reproducible to 100 ml permitted fat to be estimated with ± 0.488 kg if the observed body volume is corrected for the measured residual lung volume. However, this precision is decreased to ± 1.52 kg when a mean residual volume of 1.250 liters is accepted to correct for body volume.

The data in Table 1 shows the means and standard deviation for body weight, body volume, and the calculated body density for each of the 14 subjects of the first group measured at 7 intervals over a 24 hour period. The greatest observed standard deviation was found in subject No. 4 who exhibited changes in body mass of ± 0.062 kg, volume ± 0.59 liters, and ± 0.004 density units. The lowest standard deviation occurred in mass and volume of Subject No. 2 (0.020 kg and 0.163 liters, respectively) while the body density had a standard deviation of ± 0.002 units. An analysis of variance for the body density unit change of all 14 subjects over the 24 hour period was performed and showed the standard deviation of a single observation to be 0.002 density units (Table 2).

Table 3 depicts the mean body weight, density and percent body fat subgrouped into 5 year age increments for all of the 173 subjects studied. Residual lung volumes were estimated for this group and the gastrointestinal gas was ignored in the calculation of body density. The data shows a progressive decline in the mean body density with age (1.060 gm/ml at ages 17 - 19 to 1.017 gm/ml at ages 65 - 69) as well as a gradual increase in body fat (19.6% at ages 17 - 19 to 38.7% for the oldest age group).

Comparisons are made in Table 4 of the body density and the fat free mass of 93 males between the ages of 20 - 40 years from the group of 173 subjects studied, with that as reported by several investigators and collated by Behnke (16). The mean body density of the 93 males resembles the values of 31 males reported by Siri (Behnke) in this table but the fat free body weight was less for our subjects. Table 5 presents the body weight, density, and percent body fat of 60 males aged 17 - 25 years from the group of 173 subjects for comparison with earlier literature values as reported by Pascale (17) and Brozek (18). The 60 subjects exhibit the highest mean body weight (73.1 kg) and the lowest mean body density (1.059 gm/ml) which reflects a higher percent body fat (19.9%).

DISCUSSION

Calibration of the volumeter resulted in lowering Allen's (2) calibration factor slightly from 2.114 ± 0.064 to 2.100 ± 0.014 liters/cm, but improved its precision approximately 4 times. This is in agreement with a second volumeter reported by Allen (19). Garn (9) reported a greater readout volume accuracy in his volumeter by tilting the water manometer (33 cc/mm). However, such accuracy is questionable since it requires a body weight scale of comparable accuracy. Other measurements requiring improvement are the means of estimating residual lung volume and accurate determinations on quantities of intestinal gas present.

Food and water intake was ad libitum during the 24 hour diurnal study of body weight and body volume changes as shown in Table 1. These measurements were done to observe any extreme variation in body volume that could have been attributed to gastrointestinal gas. Conflicting reports by Bedell (13) and Blair, et al (14) cite gastrointestinal gas to be approximately 125 or up to 2600 ml, respectively. Chinn (20) suggested that the gastrointestinal gas production and volume followed a diurnal pattern and was predictable, reaching its lowest ebb between the hours of 10 a.m. and 12 noon. However, no such trends were observed in this study.

The greatest variation in body volume as seen in Subject No. 4 (Table 1), when coupled with body weight variation, produced a standard deviation of only ± 0.004 density unit change. A 70 kg man with a body density of 1.064 could alter his body density by 0.001 units had he consumed one liter of water, and as Durnin and Taylor (21) cite, this is equivalent to an 0.4% change in estimated percent body fat. Thus, estimates of body fat in Subject No. 4 could be over or underestimated by 1.6%, which by calculation from given data showed fat to vary from 7.29 - 10.58% of body weight (5.30 - 7.69 kg actual body fat) for one standard deviation.

Durnin and Taylor (21) measured body density by underwater weighing 5 times over a two week period in 10 subjects whose body weight varied by 0.5 kg during this period. These authors reported that the standard deviation of a single observation of body density measurement was ± 0.002 units, which is in agreement with our observations. The reproducibility of the estimated body density from body volumes measured by water displacement volumetry also falls within the prescribed limits of ± 0.005 density units set forth by Siri (22) wherein he had determined the inherent errors of such densitometric techniques.

A progressive increase in the mean body weight to age 34 is noted in Table 3, with a decline in body density which reflects increased body fat. The body density continues to decline although the body weight has decreased by approximately 10 kg at age 49. In the older age groups body density is further decreased demonstrating an increase in body fat. Fryer (23) reported information on 60 males aged 60 years or older and cited a mean body density of 1.0296 gm/ml which indicated 31.7% body fat and is comparable to the 60 - 64 year old males in Table 3.

Behnke (16) showed 20 - 40 year old males to have a rather constant fat free mass and cited the observations of several investigators (Table 4). Siri's data (as reported by Behnke) may be more reliable since he considered hydration of the body in his fat estimating equation. It is unusual that our data may be in agreement with Siri's because of the fact that the residual lung volumes were estimated for our subjects while the residual lung volumes are automatically corrected by Siri's technique. Allen (2) considered the water content of body tissues in deriving the USAMRNL fat predicting equation, however, his formula also estimates body fat as much as 2.5% higher than Siri's predicting equation.

The early data of Pascale (17) and Brozek (18) has been compared with data of the young adults from the 173 subjects in Table 5. These comparisons are of interest insofar as Pascale (17) reported a mean body density of 1.068 which represented 16.0% body fat as calculated by Allen's (2) equation. Our group of 60 soldiers were approximately 5 kg heavier and of a lowered body density which reflected a mean body fat burden of 19.9%. Brozek reported a specific gravity of 1.0695 which was corrected to a density value of 1.063 at 30 - 32°C for this group and cited 14.4% body fat; however, when Allen's equation is applied to this mean value, body fat is estimated at 18.2%.

It is noteworthy that this technique of water displacement volumetry effectively ranks population groups in different degrees of body fat independent of body weight but obviously age related. The technique is relatively simple, requires no source of electrical power and is quite useful in backward or remote population areas. It might be far more effective to rank populations studied in nutrition surveys in terms of relative fatness by this method rather than to relate skinfold thickness to standard height and weight tables since body density serves as a better index of percent body fat. Plough (24) cites that skinfold thickness measurements made in ICNND surveys (25) did not give more information than did height and weight tables alone, based on the preliminary results of such surveys. The actual estimate of percent body fat from direct water displacement volumetry may be in error in the individual but is of little consequence when the population is considered in terms of age groups.

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Table 1.

Body Weight, Volume and Density of 14 Subjects Measured 7 Times at 4 Hour Intervals

Subject	Body Weight, kg	Volume, liter	Density, gm/ml
1	79.19 ± 0.43	75.921 ± 0.479	1.043 ± 0.002
2	76.73 ± 0.02	72.429 ± 0.163	1.060 ± 0.002
3	75.29 ± 0.53	70.974 ± 0.519	1.061 ± 0.002
4	72.72 ± 0.62	67.036 ± 0.591	1.085 ± 0.004
5	72.50 ± 0.49	68.615 ± 0.440	1.056 ± 0.001
6	69.98 ± 0.24	66.497 ± 0.193	1.052 ± 0.001
7	69.83 ± 0.37	66.807 ± 0.287	1.045 ± 0.002
8	66.80 ± 0.56	63.055 ± 0.485	1.059 ± 0.002
9	64.69 ± 0.37	61.658 ± 0.360	1.049 ± 0.001
10	63.68 ± 0.54	59.750 ± 0.508	1.066 ± 0.001
11	58.23 ± 0.56	54.240 ± 0.325	1.074 ± 0.004
12	57.36 ± 0.31	53.420 ± 0.295	1.074 ± 0.002
13	57.32 ± 0.38	54.335 ± 0.226	1.055 ± 0.003
14	46.76 ± 0.22	42.964 ± 0.221	1.088 ± 0.002

Table 2.

Analysis of Variance of Diurnal Variation in Body Density of 14 Subjects at 4 Hour Intervals

Source of Variation	DF	Sum of Squares	Mean Square
Men	13	0.01741214	0.00133395
Hours	6	0.00005982	0.00000997
Residual	7	0.00034712	0.00000445
Total	97	0.01781908	

Standard Deviation of Single Observation = 0.0021 Density Units

Standard Error of Estimate = 0.0002 Density Units

Table 3.

Body Density and Per Cent Fat
In Adult Males

Age Group	n	Body Weight, kg	Density, gm/ml	% Fat
17 - 19	9	71.9 ± 14.4	1.060 ± 0.016	19.6 ± 7.0
20 - 24	35	73.6 ± 7.5	1.060 ± 0.013	19.5 ± 5.5
25 - 29	29	76.8 ± 14.0	1.053 ± 0.017	22.6 ± 7.3
30 - 34	15	85.8 ± 17.6	1.044 ± 0.013	26.3 ± 6.1
35 - 39	13	76.2 ± 10.6	1.043 ± 0.012	26.9 ± 3.6
40 - 44	25	75.4 ± 11.1	1.042 ± 0.012	27.1 ± 5.5
45 - 49	24	76.2 ± 10.0	1.038 ± 0.010	29.3 ± 4.5
50 - 54	12	75.5 ± 10.1	1.032 ± 0.026	32.8 ± 9.1
55 - 59	4	79.0 ± 10.3	1.031 ± 0.021	32.5 ± 4.8
60 - 64	5	69.7 ± 7.5	1.026 ± 0.010	34.7 ± 4.5
65 - 69	2	68.6 ± 2.1	1.017 ± 0.001	38.7 ± 0.6
Total	173			

Table 4.

Estimated Fat Free Weights on Groups of Adults

20 - 40 Years of Age from Body Density Determinations

Investigator	Year	n	Density gm/ml	Range	Fat Free Body Weight kg
			Underwater Weighing		
Behnke	1942	99	1.064	1.016 - 1.092	61.3
Osserman	1949	81	1.063	1.016 - 1.095	63.5
Brozek	1952	25	1.063	-	60.2
von Dobeln	1956	35	1.072	1.020 - 1.099	61.2
Pascale	1956	88	1.068	1.020 - 1.089	59.1
			Gas Displacement		
Siri (Behnke)	1957	31	1.051	1.014 - 1.081	61.9
			Direct Water Displacement		
USAMRNL	1960	93	1.052	1.010 - 1.094	59.1

Table 5.

Body Density and Per Cent Fat in Adult Males

Investigator	Age Group	n	Body Weight	Density gm/ml	% Fat
Pascale	17 - 25	88	68.3 ± 11.1	1.068 ± 0.012	16.0
Brozek	23 - 29	25	70.6 ± 8.3	1.063 ± 0.013	14.4
USAMRNL	17 - 25	60	73.1 ± 10.3	1.059 ± 0.013	19.9

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13. ABSTRACT

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The human body volumeter is a simple, rapid and effective device which compares favorably with the underwater weighing technique for estimating body density in large populations. The precision for estimating body fat is +0.488 kg when the residual lung volume is measured but is reduced to 1.52 kg when the volume is estimated.

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